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Magnetic resonance spectroscopy at 1.5 T with a hybrid metasurface

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Introduction Magnetic resonance spectroscopy (MRS) is a non-invasive technique for measuring the biochemical content of living tissue that can be performed with most of clinical magnetic resonance (MR) scanners. MRS studies a composition and distribution of metabolites *in vivo*. Since an *in vivo* concentration of metabolites is usually low (more than thousand times less than a prevailing water molecule content in a human tissue [1]), the proton MR signal received from the metabolites has a very low signal-to-noise ratio (SNR). A most straightforward and effective way to increase the SNR is the use of ultra-high-field MR scanners (above 3 T). As an alternative to the transition to higher fields, there is another way to increase the sensitivity of an MRS experiment, i.e., SNR, by means of local receive radiofrequency (RF) coils. However, such coils usually have a relatively large weight of an array, that sacrifices a convenience of their utilization by medical staff and patient's comfort.

In recent years, a lot of scientific effort has been devoted to the use of metamaterials, metasurfaces and devices based on them, in order to increase MRI sensitivity [2–5]. The possibility of SNR enhancement in MRS by means of metasurfaces was shown for ultra-high field [6]. Recently, a novel, tunable metasurface-inspired resonator (a so-called hybrid metasurface) was proposed for a local enhancement of the receive sensitivity of the birdcage body coil at 1.5 T [7]. This wireless structure improved image quality in MRI experiment. The current study aimed to demonstrate a feasibility of the improved MRS sensitivity at 1.5 T by means of the hybrid metasurface coupled to the transceive birdcage coil. The demonstration is based on a comparison of the metabolite spectra from a prostate phantom acquired with and without the metasurface.

2. Methods and materials. A tunable hybrid metasurface was realized by brass wires coupled to two high-permittivity dielectric slabs at both sides [7]. Distilled water was used as a dielectric media with a relative permittivity of 78 and conductivity of $\sigma = 5.55 \cdot 10^{-6}$ S/m. The hybrid metasurface was placed inside a 1.5 T Siemens Symphony MR scanner, so that the wires were parallel to the direction of the main magnetic field B_0 (z-direction in Fig. 1), and its resonant frequency was tuned to the Larmor frequency of protons in a particular scanner (63.66 MHz). A spherical MRS phantom (i.e., the prostate phantom), 11 cm in diameter, containing a composition of prostate metabolites (choline, creatine, citrate, lactate, etc.), was placed 2 cm bellow the center of the wires in the isocenter of the magnet. The birdcage body coil was used both for transmission and reception.

MR-spectra for aforementioned voxels were acquired using the single voxel spectroscopy method with water suppression. The same procedure was performed without the metasurface. Metabolite spectra were subsequently exported to jMRUI software package for MRS (http://www.jmrui.eu) and processed using Amares quantitation algorithm.

3. Results. The metabolite spectra from the three voxels in the prostate phantom in the presence and absence of the metasurface were acquired and compared (Fig. 1, left and right panels). The linewidths for the case of the metasurface present were up to 2 times higher for the creatine and choline peaks in comparison with the case without the metasurface. The SNR comparison showed an average 7.4-fold enhancement in the voxel located close to the metasurface wires (i.e., Voxel 3), that is in a good agreement with the previously reported MRI results [7]. For the central voxel (i.e., Voxel 2), the SNR gain was around 2.7, and for the bottom one (i.e., Voxel 1), no gain was detected. This fact may be explained by the poorer shimming of the main magnetic field in the presence of a huge amount of water which was used as a dielectric media in the current design of the metasurface.

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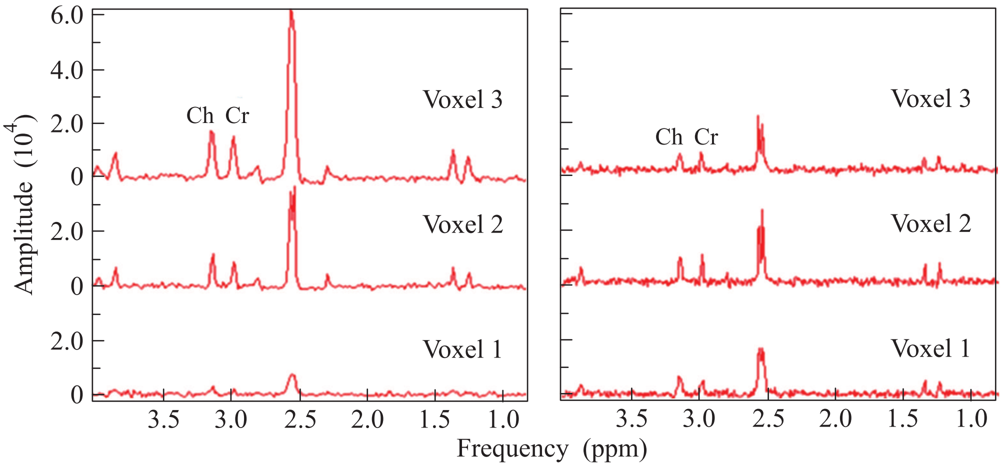

Fig. 1. (Color online) Water-suppressed MR spectra of a phantom, containing prostate metabolites, acquired from the three voxels. The voxels located in different positions along a vertical axis of a phantom: in the presence of the metasurface (left panel); and without the metasurface, i.e., when the signal was transmitted and received only by a body coil (right panel). Spectra were processed in jMRUI software package, and singlets of choline (3.2 ppm) and creatine (3 ppm) were chosen to demonstrate the influence of metasurface presence on SNR of the metabolite signals

For the first time, a feasibility of the SNR enhancement of MRS acquisitions by means of a hybrid metasurface was shown on a clinical 1.5 T MR scanner. This made possible an acquisition of the proper quality MR spectra without the expensive multi-channel local receive coils. Possible applications for a metasurface-assisted MRS are driven by the fact that the largest SNR enhancement was achieved in the area close to the metasurface. Those applications, for instance, may be musculoskeletal, human brain, or breast MRS; subcutaneous fat studies. An introduction of the metasurfaces into the clinical practice will make the MRS diagnostic method cheaper and more accessible. This will potentially increase its clinical significance. Whereas the metasurface provides the enhancement of birdcage body coil sensitivity, the current design of the hybrid metasurface was challenging to apply for human MRI and MRS studies due to the bulky design. The possible solution for miniaturization, and at the same time for avoiding B_0 distortion caused by the huge amount of distilled water, is the replacement of dielectric slabs with compact patches which has been recently described in [8].

4. Conclusion. In this letter we report on a feasibility of the significant SNR enhancement of MRS by means of a metasurface-assisted signal reception. It is a wireless and passive method that enhances both receive and transmit efficiency of a birdcage body coil in a relatively small volume. The most significant increase has been observed for the area close to the metasurface (4 cm from the wires), that makes MRS of subsurface tissues as a most promising area of the metasurface application.

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